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FLOW MEASUREMENT IN A WATER COLLECTING GALLERY BY THE CHEMICAL METHOD[1]

By D. H. Maxwell

Measurements recently made of flow in the infiltration galleries of the Des Moines Water Company are of interest as presenting a somewhat novel application of the chemical method, and showing the adaptability of this method to a situation where satisfactory discharge measurements by the velocity area method are not possible. The theory of the chemical or volumetric method is given in a paper by B. F. Groat, published in the 1914 *Proceedings of the Engineers' Society of Western Pennsylvania.* This paper is in part a review of methods developed by European enginieers. The same author last year presented a very exhaustive paper before the American Society of Civil Engineers, on the theory and practical application of the chemical method to precise testing of hydro-electric generators.

The chemical method of measuring discharge has been developed principally as applied to stream flow, particularly of mountain torrents, where current meter measurements are unsatisfactory, and for turbine testing, where its superior precision may make it preferable to other available methods. The extreme refinement used to secure high precision in turbine testing is apt to obscure the usefulness of this method in many cases where great precision is not required, and where it can be readily and cheaply used to advantage. It has a distinct field, for instance, in measuring flow in submerged conduits inconvenient of access, or in which the velocity is so moderate as to be practically outside the range of the current meter, as in the case of the Des Moines infiltration galleries.

Description of galleries. The total length of gallery completed and in use at the time of the test was 8480 feet. Manholes are provided about 600 feet apart. These galleries are built at a depth of from 20 to 25 feet in the very extensive and uniform coarse sand deposits of the Raccoon River valley, and are submerged 5 to 10 feet at low water. The newer part, 5160 feet in length, is built of concrete rings and has a cross-section of 12.6 square feet. The older galleries are rectangular and vary from 15 to 20 square feet in cross-section. When yielding at the rate of the present maximum pumpage, 14,000,000 gallons per day, the average velocity at the lower end of the main gallery is only 0.9 foot per second, the velocity decreasing progressively to practically zero at the far end.

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[1] Read at a meeting of the Illinois Section at Urbana on March 14, 1917.

The location of the two main gallery lines with reference to the river, the principal source of supply, is shown in Figure 1. The variation in distance from gallery to river, and the long continued use of the older galleries near or underneath the channel, with consequent clogging of the overlying sand, made it reasonable to suppose that the yield was not constant throughout the gallery length.

Purpose of test. In planning for the future extension of this supply, it was important to know the amount of variation in yield between different parts of the gallery from these causes. Measurements by current meter, made two years ago, were not entirely satisfactory because of the very low velocities in the gallery, and the difficulty of determining the average velocity of the cross-section. When the subject again came up for study last year, it was decided to measure the flow by the chemical method, as better adapted to the conditions.

Method of measuring flow. The test consisted in feeding a solution containing a known amount of salt (sodium chloride) at constant rate into one branch of the galleries near its upper end, and titrating for chlorine in samples of the gallery water collected at all manholes between the dosing point and the pumping station, including a sample at the pumps, just before the water entered the Venturi meter. The chlorine determinations were expressed in parts per million. These determinations, corrected for normal chlorine, indicated the dilution at any given point, of the salt fed into the gallery, and gave a measure of the flow at the corresponding point.

The equation for flow at any point is:

$$Q = \frac{C - c_2}{c_2 - c_1} q$$

in which Q is the gallery flow, q is the rate of dosing, C the concentration of the dosing solution, c_1 the normal concentration of chlorine in the gallery water, and c_2 the concentration of chlorine in the gallery water at the sampling point, after dosing.

The volume of the dose was so small in comparison with the gallery flow, that it was ignored except to keep it constant. In other

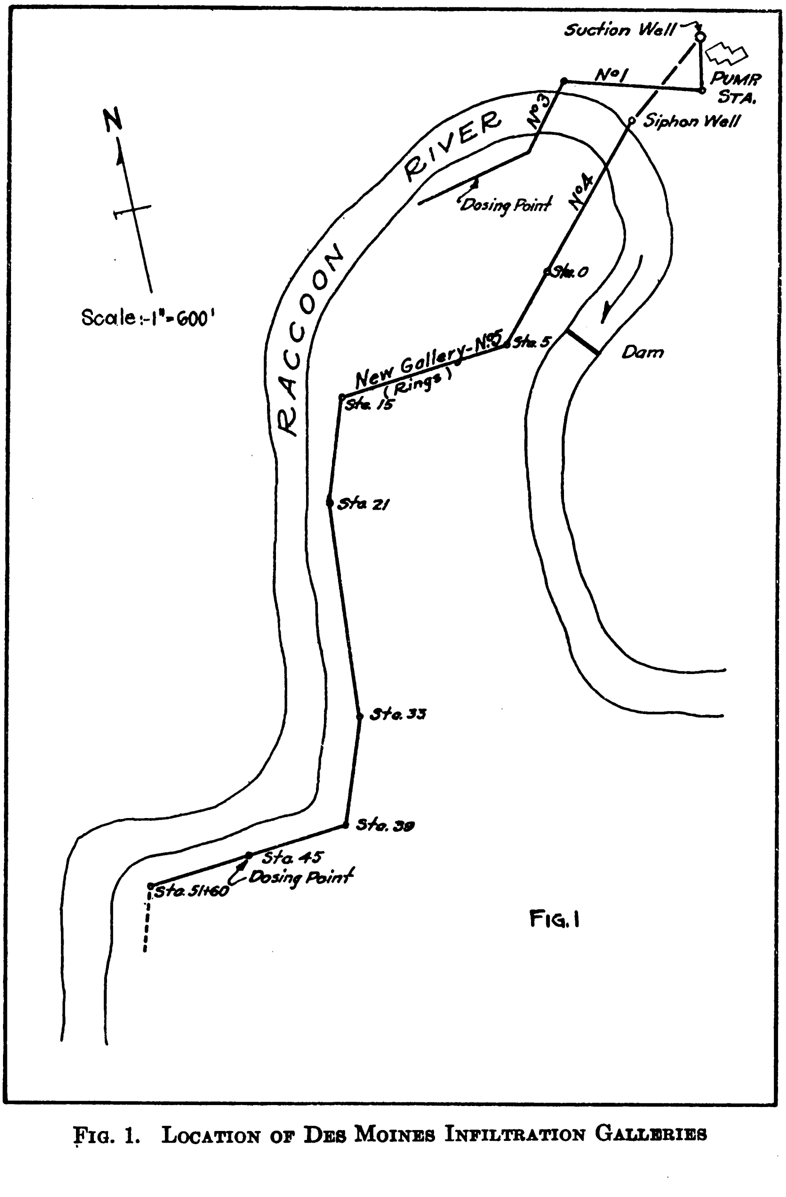

FIG. 1. LOCATION OF DES MOINES INFILTRATION GALLERIES

words, the salt used in making up the solution was carefully measured and was always added to the same quantity of water, but the exact amount of water in the solution was not determined.

Having determined the rate of flow at each manhole, the difference between the flows at successive manholes gives the total infiltration rate of the gallery intervening, and this divided by the length gives the average yield per unit length. This enables us to compare in rate of yield the several lengths of the gallery as divided by the manholes.

The ideal condition for this test, of perfectly uniform draft on the galleries, could not be secured. Des Moines has a direct pressure system and the pumpage fluctuates more or less continually. It was not practicable to overcome this difficulty by taking simultaneous samples at the several sampling points, so the test was continued during the greater part of the day, and the results used over selected periods of comparatively uniform pumpage, as shown by the Venturi meter chart. In this way the results are based upon observations made under conditions approaching as nearly as possible the ideal of steady uniformly accelerated flow, that would pertain under constant draft. It is apparent that any departure from this condition would, in the absence of simultaneous samples, give a false indication of the amount of infiltration between sampling points.

A check on the total yield of the galleries computed by this method was furnished by the Venturi meter. In fact, having the Venturi meter record of the total flow, it would not have been necessary for the purpose of this test to know the rate at which salt was added, although it was desirable to have this and use the meter as a check. The chlorine determinations might have been used merely to measure relative flow, and then compared with the chlorine determination at the Venturi meter and the flow as measured by the meter to compute the actual flow at any sampling point.

Details of test. Commercial sodium chloride was used for this work. The solution was prepared by dissolving 57 pounds of salt in about 35 gallons of water, as needed in each of two barrels from which the solution was drawn alternately. Each barrel was emptied in about thirty minutes. The barrels were piped into an orifice box, the water level in which operated a float valve controlling the barrel discharge. A $\frac{3}{16}$ inch orifice was provided under about 4 feet head, the idea in using a small orifice and large head being to minimize the effect on the discharge of the slight fluctuations in head that were unavoidable with the float valve used. A 1-inch drop pipe with funnel at the upper end caught the solution below the orifice and delivered it to the center line of the gallery.

The dosing apparatus was not entirely satisfactory. Its principal defect was the imperfect arrangement for maintaining constant head on the orifice, and absolute uniformity of feeding could not be secured with it. Some trouble was also experienced with small splinters in what appeared to be perfectly clean salt becoming lodged across the orifice. This was overcome by straining the solution through cheese cloth as it entered the orifice box. This trouble with the feeding apparatus was the principal source of error in the work.

The quantity of salt used and the size of the orifice were predetermined to approximate the desired chlorine determinations in the final sample at the pumping station.

The dose was applied in the case of the main gallery test at a point 600 feet from the upper end, with satisfactory results. The average velocity at this point during the test was about 0.113 foot per second. In testing the shorter gallery, the dose was applied only 350 feet from the dead end, and the results seemed to indicate that the velocity at this point (about 0.03 foot per second) was too low for very satisfactory results.

Sampling. Samples were collected at intervals of about one hour throughout the test, in 200-cc. bottles which were lowered into the manholes and opened as nearly as possible at the gallery center line. This precaution was necessary as at all the manholes there was considerable water standing in the shaft above the gallery, and this water doubtless lagged behind the main gallery stream in chlorine content. The care required in taking the sample and the distance apart of the half dozen or more sampling points, made it impracticable to take simultaneous samples, which would have made it possible to have conducted the test in less time.

Chlorine determinations. The samples were titrated with silver nitrate.

In the main gallery test it was observed that during constant pumpage the chlorine determinations at each sampling point continued practically constant (Fig. 2), giving a series of approximately parallel lines for the several sampling points. These values were averaged for each point.

In testing the shorter gallery, the dose, as already mentioned, was applied at a point where the velocity was evidently too low for the best results. Diffusion of the salt interfered with the appearance of constant chlorine concentration at the sampling points, even under constant draft on the gallery, and somewhat obscured the results.

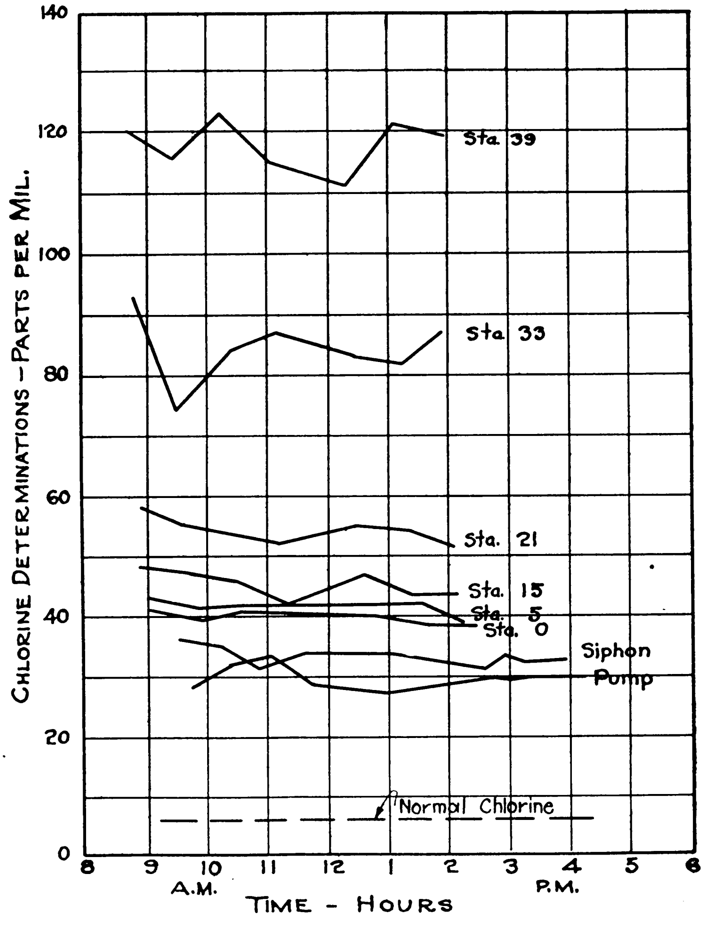

FIG. 2. CHLORINE DETERMINATIONS IN MAIN GALLERY

Results of test. The results of the tests are shown on Fig. 3. The infiltration rates under constant draft on the galleries varied from 0.20 to 1.25 gallons per minute per foot length of gallery. By comparison with the plan showing gallery location (Fig. 1) it will be seen that the low rates were found in those sections of the gallery not adjacent to the river.

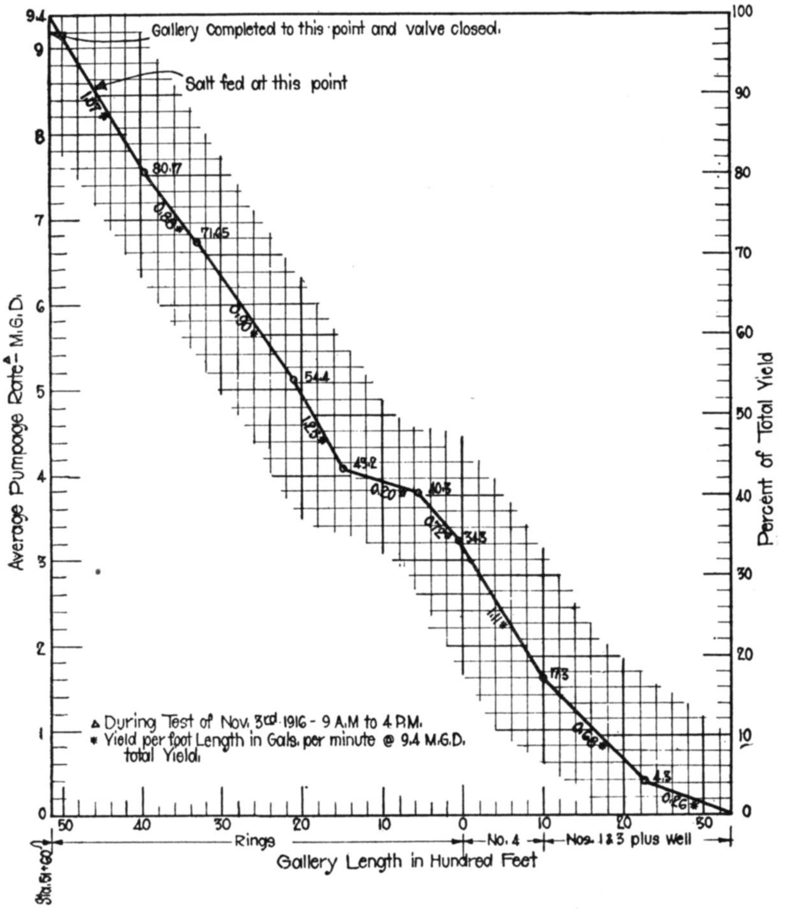

FIG. 3. YIELD OF DES MOINES INFILTRATION GALLERIES

The test was carried out in coöperation with Robert N. Kinnaird, superintendent, and E. T. Kirkpatrick, chemist, of the Des Moines Water Company, and was greatly facilitated by the admirable laboratory equipment of the company.

DISCUSSION

John W. Alvord: It may be of interest to outline something of the circumstance which required this investigation described by the author. The city of Des Moines obtains its water supply from a collecting gallery running in a remarkable formation of coarse sand and gravel beneath the Raccoon River valley. Ordinarily the filter gallery is looked upon by most sanitary engineers with suspicion, and in many cases it has undoubtedly failed to permanently produce water in sufficient quantities for the needs of the community for which it was projected. The Des Moines gallery, however, has proved to be an exception to this rule. This largely occurs because low floods on the Raccoon River clean off the sand beds of that river, and allow more or less permanent filtration to proceed.

Inasmuch as a very large monetary investment was under contemplation for these galleries, it became necessary to determine whether the present investment had met all the expectations formed for it. As it was impossible to measure the flow by any ordinary means, the interesting experiment related by the author was successfully tried. This has demonstrated that the gallery system as applied in this locality is permanent, valuable, and feasible.